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MEMORANDUM REPORT NO. 2215

A COMPUTER PROGRAM TO CALCULATE THE PHYSICAL PROPERTIES OF A SYSTEM OF COAXIAL BODIES OF REVOLUTION

by

G. P. Neitzel

August 1972

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BALLISTIC RESEARCH LABORATORIES

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 2215

GPNeitzel/mjm
Aberdeen Proving Ground, MD
August 1972

A COMPUTER PROGRAM TO CALCULATE THE PHYSICAL PROPERTIES OF A SYSTEM OF COAXIAL BODIES OF REVOLUTION

ABSTRACT

A computer program to calculate the mass, center of gravity location, and moments of inertia of a system of coaxial bodies of revolution is presented. The derivation of equations used by the program, instructions for setting up inputs, and a sample case are also given.

TABLE OF CONTENTS

LIST OF SYMBOLS

a_0, a_1	y-intercept and slope of a straight line, respectively
I_{cg}	transverse moment of inertia about the center of gravity
I_x, I_y, I_z	moments of inertia about the x, y, and z axes
m	mass
r, θ	polar coordinates used in transformation of y-z plane
R	radius of a circular arc
x, y, z	right-handed, orthogonal coordinate system
x_{cg}	center of gravity position along x-axis
x_o, x_f	lower and upper bounds, respectively, of surface along x-axis
ρ	density

Subscripts

c	coordinates of center of circular arc
i	value for segment of body
t	total value for body
u, ℓ	upper and lower surfaces, respectively

I. INTRODUCTION

When designing a projectile, one must consider not only the exterior configuration of the body, but its physical properties as well, since these will directly influence the flight behavior of the shell. By physical properties we mean mass, center of gravity location and the axial and transverse moments of inertia. It is possible to compute these properties manually, but this task for a relatively complex projectile is a very tedious one. The program described in this report (coded by D. Solmon) enables the designer to obtain accurate values for the physical characteristics of his designs with minimum effort.

Minimization of user effort necessarily implies some constraints. However, the constraints to be applied must not seriously degrade the ability of the program to handle complex bodies. With this in mind, one major assumption was made in designing this program; namely, that objects to be considered by this program will consist of coaxial bodies of revolution only. More generalized programs are available which handle the asymmetric case, but which also require more work on the part of the user[1*].

This report presents the derivation of the equations used by the program and instructions for setting up the inputs. A sample case is included for illustrative purposes. A complete listing of the program with all subroutines may be found in the Appendix.

II. DERIVATION OF EQUATIONS

Consider an axisymmetric shell of uniform density (Figure 1) having the x-axis as its axis of symmetry. The shell is bounded radially by r_ℓ and r_u (where r_ℓ and r_u are functions of x and $r_\ell \equiv y_\ell$ and $r_u \equiv y_u$ in the x-y plane) and in the x-direction by x_o and x_f (where x_o is not necessarily located at the origin as shown in Figure 1).

*References are listed on page 21.

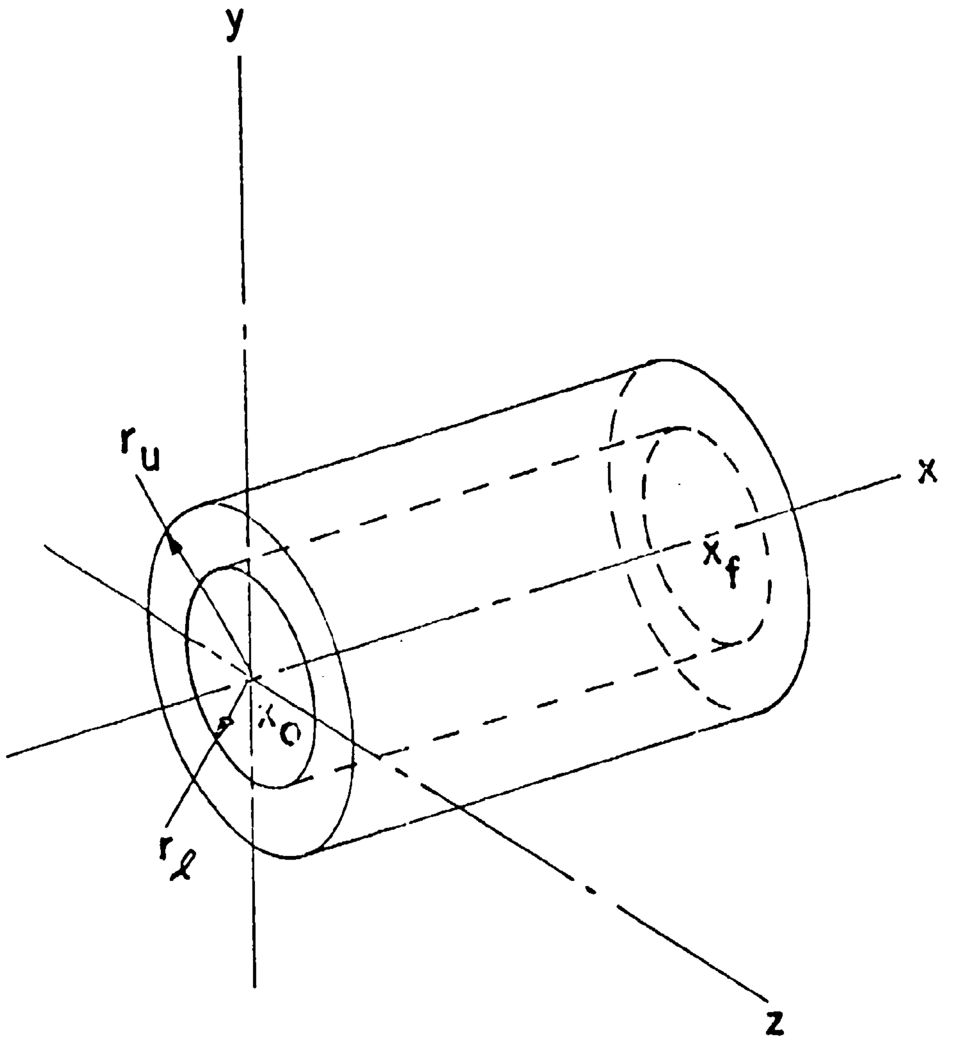

Figure 1. Coordinate System with Body Along x-Axis

A. Mass and Center of Gravity Location

In general, we know that for uniform density[2]

$$m = \int dm = \rho \int \int \int dx\, dy\, dz.$$

Transforming the y-z plane to polar coordinates and setting the limits of integration, we get

$$dy\, dz = r\, dr\, d\theta,$$

$$m = \rho \int_{x_o}^{x_f} \int_0^{2\pi} \int_{y_\ell}^{y_u} r\, dr\, d\theta\, dx,$$

which reduces to

$$m = \pi\rho \int_{x_o}^{x_f} (y_u^{\,2} - y_\ell^{\,2})\, dx.$$

We also know that

$$x_{cg} = \frac{\int x\, dm}{\int dm},$$

therefore,

$$x_{cg} = \frac{\int_{x_o}^{x_f} (y_u^{\,2} - y_\ell^{\,2})\, x\, dx}{\int_{x_o}^{x_f} (y_u^{\,2} - y_\ell^{\,2})\, dx}$$

To calculate the total mass and center of gravity location for a composite body, we first calculate the mass and center of gravity location for each section (m_i, x_{cg_i}) and use the following relations:

$$m_t = \sum_i m_i$$

$$x_{cg_t} = \frac{\sum_i m_i\, x_{cg_i}}{m_t}$$

B. Moments of Inertia

The principal moments of inertia can be defined by[2]

$$I_x = \rho \int \int \int (y^2 + z^2)\, dx\, dy\, dz,$$

$$I_y = \rho \int \int \int (x^2 + z^2)\, dx\, dy\, dz,$$

$$I_z = \rho \int \int \int (x^2 + y^2)\, dx\, dy\, dz,$$

where I_x, I_y, and I_z are the moments of inertia about the x, y, and z axes respectively. For an axisymmetric body whose axis of symmetry is the x-axis,

$$I_y = I_z.$$

1. Axial Moment of Inertia.

$$I_x = \rho \int \int \int (y^2 + z^2)\, dx\, dy\, dz.$$

Transforming to polar coordinates and setting limits of integration,

$$I_x = \rho \int_{x_o}^{x_f} \int_{0}^{2\pi} \int_{y_\ell}^{y_u} r^3\, dr\, d\theta\, dx$$

therefore,

$$I_x = \frac{\pi\rho}{2} \int_{x_o}^{x_f} (y_u{}^4 - y_\ell{}^4)\, dx.$$

For a composite body,

$$I_{x_t} = \sum_i I_{x_i}.$$

2. Transverse Moment of Inertia.

$$I_y = I_z,$$

therefore,

$$2\, I_y = I_y + I_z = \rho \int \int \int (2x^2 + y^2 + z^2)\, dx\, dy\, dz.$$

$$I_y = \rho \int \int \int x^2\, dx\, dy\, dz + \frac{\rho}{2} \int \int \int (y^2 + z^2)\, dx\, dy\, dz$$

$$= \rho \int \int \int x^2\, dx\, dy\, dz + \frac{1}{2}\, I_x.$$

Transforming to polar coordinates and setting limits of integration,

$$I_y = \frac{1}{2} \quad I_x + \rho \int_{x_o}^{x_f} \int_0^{2\pi} \int_{y_\ell}^{y_u} x^2 \, r \, dr \, d\theta \, dx,$$

therefore,
$$I_y = \frac{1}{2} I_x + \pi\rho \int_{x_o}^{x_f} (y_u{}^2 - y_\ell{}^2) \, x^2 \, dx.$$

For a composite body, the total moment of inertia about the y (or z) axis is given by

$$I_{y_t} = \sum_i I_{y_i}.$$

To get the total transverse moment of inertia about the center of gravity, we use

$$I_{cg_t} = I_{y_t} - m_t \, x_{cg_t}{}^2.$$

III. USE OF THE PROGRAM

As previously stated, this program assumes a system of coaxial bodies of revolution. If the x-axis is chosen as the axis of symmetry, then the surfaces of the body may be generated by rotating $y = f(x)$ about the x axis. The origin is usually taken (a) at the nose, with the positive x-axis pointing rearward or (b) at the base, with the positive x-axis pointing forward. The center of gravity is computed from the chosen origin. As presently constructed, the program will handle two types of functions; circular arcs and straight lines. Circular arcs are of the form

$$y = y_c \pm \sqrt{R^2 - (x - x_c)^2},$$

where (x_c, y_c) is the location of the center, and R is the radius. Some care must be taken to insure that the quantity under the radical sign is never negative in the applicable x-interval. (The quantity could go negative near $|x-x_c| = R$, due to round-off errors.) Taking the origin at the nose will usually circumvent this problem.

Straight lines are of the form

$$y = a_0 + a_1 x,$$

where a_0 and a_1 are the y-intercept and slope respectively. Associated with each function is an interval, (x_o, x_f), within which it is applicable, and the density, ρ, of the area lying immediately below the function within the interval.

Each function is input on a single data card. The cards may be arranged in any order, with a blank card following the last data card of a case. Cases may be stacked. The data cards are of the following form, with data fields being ten columns. Decimal points must be punched.

A. Circular Arcs

Card Columns	Content
1-10	x_c
11-20	y_c
21-30	R
31-40	x_o
41-50	x_f
51-60	ρ
61-78	alphanumeric code for identification of output
79	blank for $y = y_c + \sqrt{\quad}$
	- for $y = y_c - \sqrt{\quad}$
80	1

B. Straight Lines

Card Columns	Content
1-10	a_0
11-20	a_1
21-30	x_o
31-40	x_f
41-50	blank
51-60	ρ
61-78	alphanumeric code for identification of output
79	blank
80	2

Care should be taken to insure that the units of measurement used for density are consistent with the units of length used on the drawing from which the functions were derived.

The program prints out the input data, for checking purposes, as well as the computed values of mass, center of gravity location, and axial and transverse moments of inertia. The units of these computed values are dependent upon the units of the input data.

IV. SAMPLE CASE

The sample case, shown in Figure 2, is the 105mm, HE, M1 artillery projectile with M73 dummy fuze. The shape is rotationally symmetric except for two fuze wrench slots on the M73 which were ignored for present purposes. The densities of the various materials which make up the round are listed in Table 1.

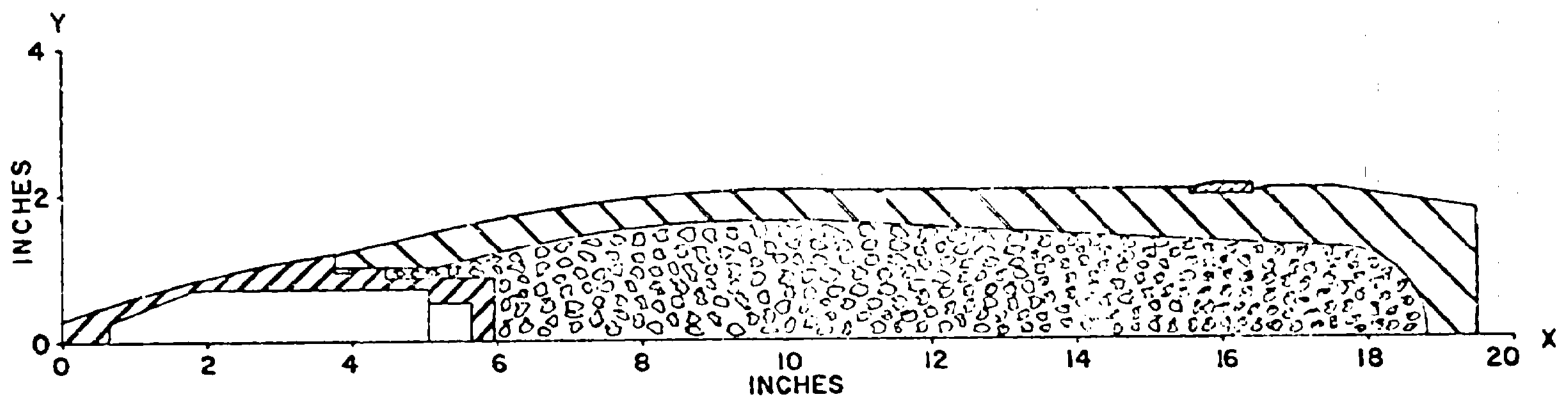

Figure 2. 105mm, HE, M1 with M73 Dummy Fuze

Table I. Densities of Materials Used for Sample Case

Section	Material	Density (lb/in^3)
Fuze	Steel	.2833
Body	Steel	.2833
Base Plate	Steel	.2833
Rotating Band	Gilding Metal	.3128
H.E. Filler	Comp B	.0549

Tabulations of input and output are shown in Tables II and III respectively. A comparison of computed values with standard values is given in Table IV. The computed values are in good agreement with the standard values with the maximum error (+2.8%) occurring in the transverse moment of inertia computation. Keep in mind, however, that these standard values are the mean values of measurements taken on a sample of production rounds whose actual shapes may vary slightly from standard. This sample case was selected to give the reader an idea of the degree of complexity which can be handled by the program. For known shapes with known densities, the computation is nearly exact (within the tolerance imposed on the integration routine).

Table II. Inputs for Sample Case

1-10	11-20	21-30	31-40	41-50	51-60	61-78	80
7.155122	-26.[illegible]	22.	0.	[illegible].76	.2833	105MM M1 TEST CASE	1
.93	0.	[illegible].76	3.96		.2833	105MM M1 TEST CASE	2
1.	0.	3.96	4.46		.2833	105MM M1 TEST CASE	2
.85	0.	4.46	5.96		.2833	105MM M1 TEST CASE	2
-.007899	.390756	.66	1.77		0.	105MM M1 TEST CASE	2
1.92	0.	.7	1.77	1.92	0.	105MM M1 TEST CASE	1
.7	0.	1.92	5.04		0.	105MM M1 TEST CASE	2
.5	0.	5.04	5.64		0.	105MM M1 TEST CASE	2
10.433179	-23.421353	25.5	3.76	9.54	.2833	105MM M1 TEST CASE	1
2.063	0.	9.54	10.54		.2833	105MM M1 TEST CASE	2
2.045	0.	10.54	15.54		.2833	105MM M1 TEST CASE	2
-1.288581	.214516	15.54	15.85		.3128	105MM M1 TEST CASE	2
2.1115	0.	15.85	16.41		.3128	105MM M1 TEST CASE	2
1.97	0.	15.54	16.41		.2833	105MM M1 TEST CASE	2
2.03	0.	16.41	16.51		.2833	105MM M1 TEST CASE	2
-3.158857	.314286	16.51	16.61		.2833	105MM M1 TEST CASE	2
2.063	0.	16.61	17.46		.2833	105MM M1 TEST CASE	2
4.708190	-.1515	17.46	19.46		.2833	105MM M1 TEST CASE	2
1.505	0.	19.46	19.49		.2833	105MM M1 TEST CASE	2
1.	0.	3.76	3.96		0.	105MM M1 TEST CASE	2
1.	0.	4.46	5.15		.0549	105MM M1 TEST CASE	2
9.525438	-13.347667	15.	5.15	9.79	.0549	105MM M1 TEST CASE	1
9.79	-16.35	16.	9.79	10.78478	.0549	105MM M1 TEST CASE	1
2.212444	-.054702	10.78478	17.62908		.0549	105MM M1 TEST CASE	2
17.56	0.	1.25	17.62908	18.81	.0549	105MM M1 TEST CASE	1
blank							

TABLE III. Output for Sample Case

A_0	A_1	W_C	Y_C	R	X_O	X_F	DENSITY	COMMENTS
0.00000E 00	0.00000E 00	0.71551E 01	-0.20524E 02	0.22000E 02	0.00000E 00	0.37600E 01	0.28330E 00	105MM M1 TEST CASE
0.93000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.37600E 01	0.39600E 01	0.28330E 00	105MM M1 TEST CASE
0.10000E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.39600E 01	0.44600E 01	0.28330E 00	105MM M1 TEST CASE
0.85000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.44600E 01	0.59600E 01	0.28330E 00	105MM M1 TEST CASE
-0.78990E-02	0.39076E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.66000E 00	0.17700E 01	0.00000E 00	105MM M1 TEST CASE
0.00000E 00	0.00000E 00	0.19200E 01	0.00000E 00	0.70000E 00	0.17700E 01	0.19200E 01	0.00000E 00	105MM M1 TEST CASE
0.70000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.19200E 01	0.50400E 01	0.00000E 00	105MM M1 TEST CASE
0.50000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.50400E 01	0.56400E 01	0.00000E 00	105MM M1 TEST CASE
0.00000E 00	0.00000E 00	0.10433E 02	-0.23421E 02	0.25500E 02	0.37600E 01	0.95400E 01	0.28330E 00	105MM M1 TEST CASE
0.20630E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.95400E 01	0.10540E 02	0.28330E 00	105MM M1 TEST CASE
0.20450E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.10540E 02	0.15540E 02	0.28330E 00	105MM M1 TEST CASE
-0.12886E 01	0.21452E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.15540E 02	0.15850E 02	0.31280E 00	105MM M1 TEST CASE
0.21115E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.15850E 02	0.16410E 02	0.31280E 00	105MM M1 TEST CASE
0.19700E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.15540E 02	0.16410E 02	0.28330E 00	105MM M1 TEST CASE
0.20300E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.16410E 02	0.16510E 02	0.28330E 00	105MM M1 TEST CASE
-0.31589E 01	0.31429E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.16510E 02	0.16610E 02	0.28330E 00	105MM M1 TEST CASE
0.20630E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.16610E 02	0.17460E 02	0.28330E 00	105MM M1 TEST CASE
0.47082E 01	-0.15150E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.17460E 02	0.19460E 02	0.28330E 00	105MM M1 TEST CASE
0.15050E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.19460E 02	0.19490E 02	0.28330E 00	105MM M1 TEST CASE
0.10000E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.37600E 01	0.39600E 01	0.00000E 00	105MM M1 TEST CASE
0.10000E 01	0.00000E 00	0.00000E 00	0.00000E 00	0.00000E 00	0.44600E 01	0.51500E 01	0.54900E-01	105MM M1 TEST CASE
0.00000E 00	0.00000E 00	0.95214E 01	-0.13348E 02	0.15000E 02	0.51500E 01	0.97400E 01	0.54900E-01	105MM M1 TEST CASE
0.00000E 00	0.00000E 00	0.97900E 01	-0.16350E 02	0.18000E 02	0.97900E 01	0.10785E 02	0.54900E-01	105MM M1 TEST CASE
0.22124E 01	-0.54702E-01	0.00000E 00	0.00000E 00	0.00000E 00	0.10785E 02	0.17629E 02	0.54900E-01	105MM M1 TEST CASE
0.00000E 00	0.00000E 00	0.17560E 02	0.00000E 00	0.12500E 01	0.17629E 02	0.18810E 02	0.54900E-01	105MM M1 TEST CASE

MASS	CG	AX MOM	TRANS MOM	CODE
0.33087E 02	0.12291E 02	0.80453E 02	0.79218E 03	105MM M1 TEST CASE

Table IV. Comparison of Standard and Computed Values for Sample Case

Quantity	Units	Stand.	Computed	Error (%)
Mass	lb	33.0	33.087	+0.3
Center of Gravity (from nose)	in	12.264	12.291	+0.2
Axial Mom.	$lb\text{-}in^2$	79.488	80.453	+1.2
Trans. Mom.	$lb\text{-}in^2$	770.803	792.18	+2.8

REFERENCES

1. E. B. Lacher, "Moments: A Computer Program to Calculate Moments and Products of Inertia of Asymmetric Shells and Other Bodies," Picatinny Arsenal Technical Report No. 4143, AD 730682, July 1971.

2. K. R. Symon, *Mechanics (second edition)*, Addison-Wesley Publishing Company, Inc., 1960.

APPENDIX

```
      DIMENSION ICODE(40), XC(40), YC(40), RC(40), A0(40), A1(40),
     1 XO(80), XF(80), RO(40), XOP(80), X(80), XT(80), FY(40), MN(40),
     2 NFUN(40), XL(40), XU(40)
      COMMON XC, YC, RC, A0, A1, NUP, NLO, FLIP, ICODE
      EXTERNAL FX
      PI=3.141592654
C
C     INITIALIZATIONS
C
    1 ZF=0.
      XM=0.
      AMI=0.
      BB=0.
      A0(1)=0.
      A1(1)=0.
      XC(1)=0.
      YC(1)=0.
      RC(1)=0.
      RO(1)=0.
      XO(1)=0.
      XF(1)=0.
C
C     READ INPUT, REARRANGE IF NECESSARY, AND PRINT OUT.
C
      DO 5 I=2,100
      READ (5,28) XC(I),YC(I),RC(I),XO(I),XF(I),RO(I),(ACODE(K),K=1,2),
     1 ICODE(I)
      IF (ICODE(I).EQ.0) GO TO 6
      AACODE=ACODE(1)
      ABCODE=ACODE(2)
      IF (ICODE(I).NE.2) GO TO 2
      A0(I)=XC(I)
      A1(I)=YC(I)
      XF(I)=XO(I)
      XO(I)=RC(I)
      XC(I)=0.
      YC(I)=0.
      RC(I)=0.
      GO TO 3
    2 A0(I)=0.
      A1(I)=0.
    3 IF (I.GT.2) GO TO 4
      WRITE (6,31)
    4 WRITE (6,32) A0(I),A1(I),XC(I),YC(I),RC(I),XO(I),XF(I),RO(I),
     1 AACODE,ABCODE
    5 CONTINUE
      N=20
      GO TO 7
    6 N=I-1
    7 WRITE (6,29)
      LI=N
      ACODE(1)=AACODE
      ACODE(2)=ABCODE
C
C     DIVIDE BODY INTO REGIONS USING BREAK POINTS.
C
      DO 8 I=1,N
      X(I)=XO(I)
      J=N+I
    8 X(J)=XF(I)
```

```
      NN=2*N
      N=NN
      L=1
      DO 12 I=1,N
      FLOP=0.
      CALL PMIN (X,NN,XMIN,IT)
      XBP(L)=XMIN
      IF (I.EQ.1) GO TO 9
      IF (XBP(L).EQ.XBP(L-1)) FLOP=1.0
    9 J=0
      DO 10 K=1,NN
      IF (IT.EQ.K) GO TO 10
      J=J+1
      X(J)=X(K)
   10 CONTINUE
      NN=NN-1
      IF (FLOP.EQ.1.0) GO TO 11
      L=L+1
   11 CONTINUE
      IF (NN.EQ.1) GO TO 13
   12 CONTINUE
   13 CONTINUE
      IF (X(1).EQ.XBP(L-1)) GO TO 14
      XBP(L)=X(1)
      GO TO 15
   14 L=L-1
   15 CONTINUE
      XO(1)=XBP(1)
      XF(1)=XBP(L)
      I=1
   16 II=1
      XT(I)=(XBP(I)+XBP(I+1))/2.
      K=1
C
C     SEPARATE REGIONS INTO LAYERS OF UNIFORM DENSITY.
C
      DO 19 J=1,LI
      IF (XO(J).GT.XT(I).OR.XT(I).GT.XF(J)) GO TO 19
      IF (RC(J).EQ.0.) GO TO 17
      FY(K)=YC(J)+SQRT(RC(J)**2-(XT(I)-XC(J))**2)+AC(J)+A1(J)*XT(I)
      IF (ICODE(J).NE.-1) GO TO 18
      FY(K)=YC(J)-SQRT(RC(J)**2-(XT(I)-XC(J))**2)+A0(J)+A1(J)*XT(I)
      GO TO 18
   17 FY(K)=A0(J)+A1(J)*XT(I)
   18 CONTINUE
      MN(K)=J
      K=K+1
   19 CONTINUE
      K=K-1
      JJ=1
   20 CONTINUE
      IF (K.EQ.2) GO TO 22
      CALL PMAX (FY,K,XMAX,IT)
      NFUN(JJ)=MN(IT)
      ICODE(JJ)=ICODE(IT)
      J=0
      DO 21 IX=1,K
      IF (IT.EQ.IX) GO TO 21
      J=J+1
      ICODE(J)=ICODE(IX)
```

```
      FY(J)=FY(IX)
      MN(J)=MN(IX)
   21 CONTINUE
      JJ=JJ+1
      K=K-1
      GO TO 20
   22 CONTINUE
      IF (FY(1).GT.FY(2)) GO TO 23
      NFUN(JJ)=MN(2)
      ICODE(JJ)=ICODE(2)
      NFUN(JJ+1)=MN(1)
      ICODE(JJ+1)=ICODE(1)
      GO TO 24
   23 NFUN(JJ)=MN(1)
      ICODE(JJ)=ICODE(1)
      NFUN(JJ+1)=MN(2)
      ICODE(JJ+1)=ICODE(2)
   24 CONTINUE
   25 NUP=NFUN(II)
      NLO=NFUN(II+1)
      XL(I)=XBP(I)
      XU(I)=XBP(I+1)
      FLIP=0.
C
C     INTEGRATE BODY SECTION TO FIND MASS, AND ACCUMULATE.
C
      CALL RMBGIN (FX,FI,XL(I),XU(I),10.**(-6),0.)
      FLIP=1.0
      XM=XM+PI*RO(NUP)*FI
C
C     INTEGRATE BODY SECTION TO FIND C.G. LOCATION.
C
      CALL RMBGIN (FX,FFI,XL(I),XU(I),10.**(-6),0.)
      FLIP=2.0
      XCG=FFI/FI
C
C     INTEGRATE BODY SECTION TO FIND AXIAL MOMENT, AND ACCUMULATE.
C
      CALL RMBGIN (FX,GI,XL(I),XU(I),10.**(-6),0.)
      FLIP=3.0
      AMI=AMI+0.5*PI*RO(NUP)*GI
C
C     INTEGRATE BODY SECTION TO FIND TRANSVERSE MOMENT, AND ACCUMULATE.
C
      CALL RMBGIN (FX,GGI,XL(I),XU(I),10.**(-6),0.)
      ZF=ZF+FI*XCG*PI*RO(NUP)
      BB=BB+PI*RO(NUP)*(0.25*GI+GGI)
      IF (II.EQ.JJ) GO TO 26
      II=II+1
      GO TO 25
   26 I=I+1
      IF (I.EQ.L) GO TO 27
      GO TO 16
C
C     CALCULATE C.G. LOCATION AND TOTAL TRANSVERSE MOMENT.
C
   27 CGP=GJ-ZF/XM
      B=BB-XM*(CGP-GJ)**2
C
C     PRINT OUT RESULTS, AND RETURN FOR A NEW CASE.
```

```
C
      WRITE (6,30) XM,CGPROJ,AMI,B,(ACODE(I),I=1,2)
      GO TO 1
C
   28 FORMAT (6F10.6,2A5,I2)
   29 FORMAT (/5X,5H MASS,12X,2HCG,9X,6HAX MOM,7X,9HTRANS MOM,11X,4HCODE
     1/)
   30 FORMAT (4(2X,E12.5),3X,2A9)
   31 FORMAT (////7X,1HA,12X,1HA,12X,1HX,12X,1HY,12X,1HR,12X,1HX,12X,1HX
     1,9X,7HDENSITY,10X,8HCOMMENTS/8X,1HO,12X,1H1,12X,1HC,12X,1HC,25X,1HM
     20,12X,1HF/)
   32 FORMAT (1H ,8E13.5,3X,2A9)
      END
      FUNCTION FX (X)
      DIMENSION XC(40), YC(40), RC(40), A0(40), A1(40), XXC(40),
     1  ICODE(40)
      COMMON XC, YC, RC, A0, A1, NUP, NLO, FLIP, ICODE
      XXC(NUP)=X-XC(NUP)
      IF (RC(NUP).EQ.0.) XXC(NUP)=0.
      XXC(NLO)=X-XC(NLO)
      IF (RC(NLO).EQ.0.) XXC(NLO)=0.
      IF (ICODE(NUP).EQ.-1) GO TO 1
      YU=(YC(NUP)+(RC(NUP)**2-XXC(NUP)**2)**0.5+A0(NUP)+A1(NUP)*X)**2
      GO TO 2
    1 YU=(YC(NUP)-(RC(NUP)**2-XXC(NUP)**2)**0.5+A0(NUP)+A1(NUP)*X)**2
    2 CONTINUE
      IF (ICODE(NLO).EQ.-1) GO TO 3
      YL=(YC(NLO)+(RC(NLO)**2-XXC(NLO)**2)**0.5+A0(NLO)+A1(NLO)*X)**2
      GO TO 4
    3 YL=(YC(NLO)-(RC(NLO)**2-XXC(NLO)**2)**0.5+A0(NLO)+A1(NLO)*X)**2
    4 CONTINUE
      FX=YU-YL
      IF (FLIP.EQ.0.) RETURN
      IF (FLIP-2.) 5,6,7
    5 FX=X*FX
      RETURN
    6 FX=YU**2-YL**2
      RETURN
    7 FX=FX*(X**2)
      RETURN
      END
      SUBROUTINE RMBGIN (FX,FI,LL,UL,TOL,PC)
      REAL LL
      DIMENSION A(9), B(9)
      DO 1 I=1,9
      A(I)=0.
    1 B(I)=0.
      XL=LL
      FA=FX(XL)
      F=FX(UL)
      H=UL-XL
      A(1)=.5*H*(FA+F)
      IP=1
      IC=0
      IS=1
      IF (PC.EQ.0.) GO TO 2
      WRITE (6,11) H,IC,(A(I),I=1,4)
    2 IC=1
    3 H1=H
      H=.5*H
```

```
      X=XL+H                                                            RMBGN20
      SUM=0.                                                            RMBGN21
      DO 4 I=1,IS                                                       RMBGN22
      SUM=FX(X)+SUM                                                     RMBGN23
    4 X=H1+X                                                            RMBGN24
      IS=IS+IS                                                          RMBGN25
      B(1)=.5*(A(1)+H1*SUM)                                             RMBGN26
      C=4.                                                              RMBGN27
      DO 5 J=1,IP                                                       RMBGN28
      K=J+1                                                             RMBGN29
      B(K)=(C*B(J)-A(J))/(C-1.)                                         RMBGN30
    5 C=4.*C                                                            RMBGN31
      IF (PC.EQ.0.) GO TO 6                                             RMBGN32
      WRITE (6,11) H,IC,(B(I),I=1,9)                                    RMBGN33W
    6 DO 7 J=1,IP                                                       RMBGN34
      K=J+1                                                             RMBGN35
      ABC=ABS((B(J)-B(K))/B(K))                                         RMBGN36
      IF (ABC-TOL.LE.0.) GO TO 10                                       RMBGN37
      ABC=ABS((A(K)-B(K))/B(K))                                         RMBGN38
      IF (ABC-TOL.LE.0.) GO TO 10                                       RMBGN39
    7 CONTINUE                                                          RMBGN40
      IF (IP.EQ.8) GO TO 8                                              RMBGN41
      IP=IP+1                                                           RMBGN42
    8 IC=IC+1                                                           RMBGN43
      DO 9 J=1,9                                                        RMBGN44
    9 A(J)=B(J)                                                         RMBGN45
      IF (IC.LE.10) GO TO 3                                             RMBGN46
      WRITE (6,12)                                                      RMBGN47W
   10 FI=B(K)                                                           RMBGN48
      RETURN                                                            RMBGN49
C                                                                       RMBGN50
   11 FORMAT (1PE14.7,I4,9E12.5)                                        RMBGN51
   12 FORMAT (37H RMBGIN DID NOT CONVERGE IN 10 STEPS.)                 RMBGN52
      END                                                               RMBGN53-
      SUBROUTINE PMAX (X,N,XMAX,J)                                      * 274* 3
      DIMENSION X(500)                                                  PMAX   2
      XMAX=X(1)                                                         PMAX   3
      J=1                                                               PMAX   4
      DO 2 I=2,N                                                        PMAX   5
      IF (XMAX-X(I)) 1,2,2                                              PMAX   6
    1 J=I                                                               PMAX   7
      XMAX=X(I)                                                         PMAX   8
    2 CONTINUE                                                          PMAX   9
      RETURN                                                            PMAX  10
      END                                                               PMAX  11-
      SUBROUTINE PMIN (X,N,XMIN,J)                                      * 285* 4
      DIMENSION X(500)                                                  PMIN   2
      J=1                                                               PMIN   3
      XMIN=X(1)                                                         PMIN   4
      DO 2 I=2,N                                                        PMIN   5
      IF (XMIN-X(I)) 2,2,1                                              PMIN   6
    1 J=I                                                               PMIN   7
      XMIN=X(I)                                                         PMIN   8
    2 CONTINUE                                                          PMIN   9
      RETURN                                                            PMIN  10
      END                                                               PMIN  11-
C                                                                           END
*     DATA
```

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13. ABSTRACT

A computer program to calculate the mass, center of gravity location, and moments of inertia of a system of coaxial bodies of revolution is presented. The derivation of equations used by the program, instructions for setting up inputs, and a sample case are also given. (For asymmetric body technique see AD 730682).

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